Engineering Hydrology
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Module 04 - Lecture 45
Numerical Examples on Excess Rainfall/Direct Runoff

Hello all, welcome back. In the previous lecture, we were discussing about the excess rainfall and the corresponding direct runoff. We have seen different methods for estimation of excess rainfall. So, different methods we have seen in the previous lecture are $\phi - index$ method, infiltration methods, runoff coefficient and also SCS curve number method. We will start with the $\phi - index$ method.

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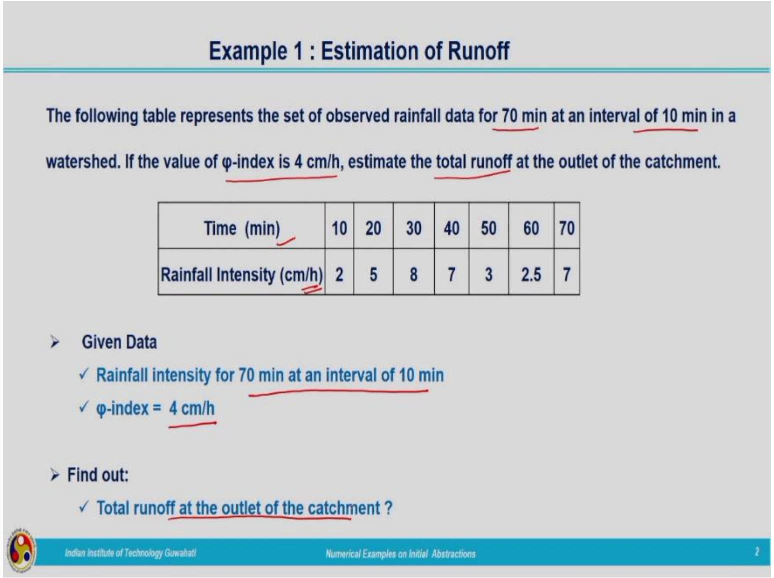

So, example one is related to estimation of runoff. So, let me first read out the question. The following table represents the set of observed rainfall data for 70 minutes at an interval of 10 minutes in a watershed. If the value of $\phi - index$ is 4 centimetres per hour, estimate the total runoff at the outlet of the catchment. So, the rainfall data is tabulated over here, time is given in minutes and rainfall intensity is given in centimetres per hour. So, you need to be very careful, intensity is in centimetres per hour and time is given in minutes.

Now, let us solve the problem, before that let us revisit into the data given rainfall data for 70 minutes at an interval of 10 minutes given to us. $\phi - index$ is 4 centimetres per hour is also given to us. So, we know if $\phi - index$ is there, how to compute the runoff depth. $\phi - index$ is representing the constant rate of abstraction from a catchment. So, once that data is available to us corresponding to that how much is the quantity of water which is lost as abstraction can be calculated. Once we deduct that value from the total rainfall data we will get the corresponding excess rainfall which is equivalent to the direct runoff depth. So, we need to find out the total runoff at the outlet of the catchment.

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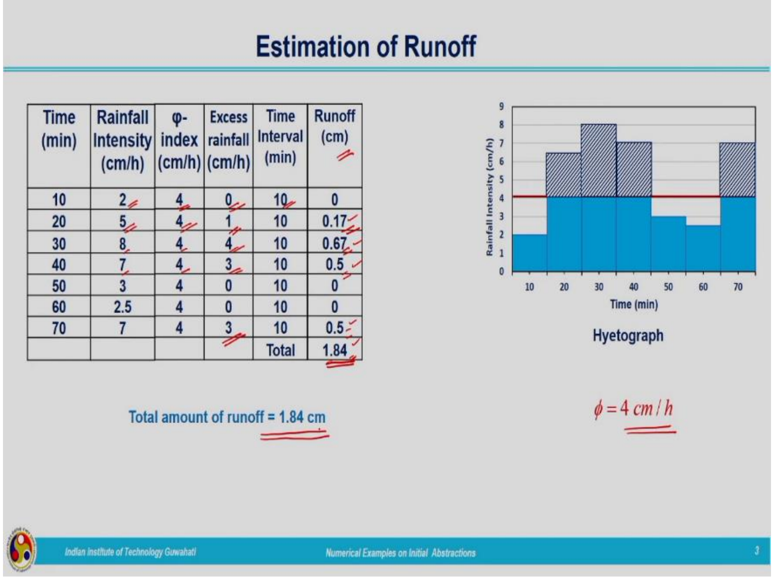

So, with the given data, given data is time and rainfall intensity. So, with that we can draw the rainfall hyetograph. That is already plotted here. Hyetograph is shown over here in this graph and the data which is given to us is 4 centimetre per hour is the value corresponding to abstractions which is given as the $\phi - index$ value. So, that is tabulated in this column, 4 centimetres per hour can be marked over the graph like this. So, this is a constant rate of abstraction. So, it will be a straight line all throughout the time period. So, you can see 4 centimetre per hour which is representing the $\phi - index$ value is demarcating the excess rainfall and the abstractions.

So, here we can understand that the rainfall which is coming above the $\phi - index$ value will be contributing to the direct runoff which is marked over here by the dashed lines. So, excess rainfall we can calculate So, you can observe the data. For the first 10 minutes: 0 to 10 minutes, 2 centimetre per hour is our rainfall data, $\phi - index$ is 4 centimetres per hour. So, the constant rate of abstraction is more than that of the rate of rainfall. So, definitely whatever rainfall is occurring, everything is lost as abstraction. It may be in the form of initial abstraction or it may be in the form of infiltration. So, 2 centimetres per hour is the rainfall intensity and 4 centimetres per is the $\phi - index$. So, excess rainfall will be 0 and second case that is from 10 to 20 minutes, we got the rainfall of 5 centimetres per hour and $\phi - index$ is 4.

So, the difference between them will be giving us the excess rainfall corresponding to that time period that is 1 centimetres per hour. In that way for the next time period it will be 8 minus 4 that is equivalent to 4 centimetres per hour. For 30 to 40 minutes it will be 7 and 4, i.e.,7 minus 4 and it is 3 centimetres per hour. That way we can calculate the excess rainfall depth.

So, for all the time intervals we have computed the excess rainfall. Now, the time interval is 10 minutes gap, so, the intensity is given in centimetres per hour and the time interval corresponding to each intensity is 10 minutes. So, both the units of time should be made to same unit. So, corresponding to this excess rainfall centimetres per hour is there with us. So, corresponding to this time interval we need to calculate one centimetre per hour for 10 minutes, so that when we convert it into centimetres, we will get 0.17 centimetres and in the similar way corresponding to all the time intervals we will compute the runoff depth.

So, certain time intervals are not contributing towards runoff, those values are being taken as the abstractions and remaining which is coming above the $\phi - index$ value is contributing towards the runoff at the outlet. So, we got the runoff depth corresponding to each time interval. So, those values will be added together to get the total runoff at the outlet of the catchment and that is coming out to be 1.84 centimetres. Once the depth of water corresponding to each interval which is going as the abstraction is calculated that when deducted from the total rainfall will be giving us the runoff depth. So, the total amount of runoff which is calculated is 1.84 centimetre related to this problem.

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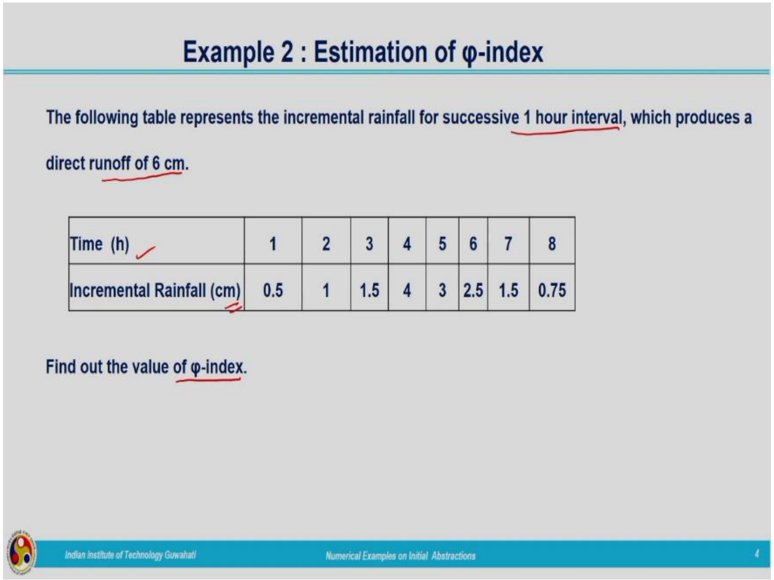

Time (h)	1	2	3	4	5	6	7	8
Incremental Rainfall (cm)	0.5	1	1.5	4	3	2.5	1.5	0.75

Now, let us move on to the second example. First example was very simple because directly the $\phi-index$ value is given to you and rainfall hyetograph is given to you. Now, second one is estimation of $\phi-index$. In this case definitely you need to be given the runoff depth. So, this $\phi-index$ method is applicable to gauged catchments. So, from the measured runoff depth value and the rainfall depth value, we will be calculating the $\phi-index$ or the constant rate of abstractions which may happen from a particular watershed.

The following table represents the incremental rainfall for successive 1-hour interval which produces a direct runoff of 6 centimetres. So, the rainfall data is representing corresponding to 1-hour time interval and the runoff which is produced direct runoff is 6 centimetres. The rainfall data is tabulated here in this particular table, time in hours and incremental rainfall depth in centimetres given to you and runoff depth is 6 centimetres. This rainfall is producing a runoff of 6 centimetre set the outlet of the basin, we need to calculate the $\phi-index$ value.

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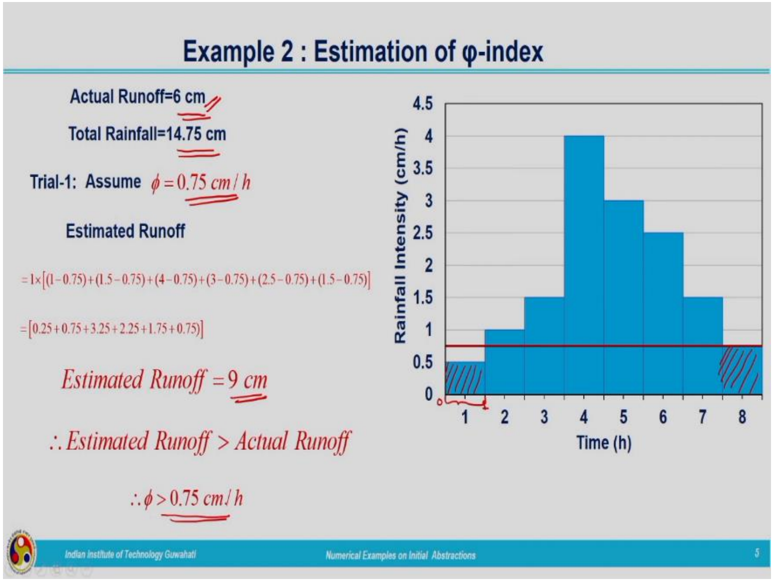

The data given actual runoff 6 centimetres and total rainfall 14.75 centimetre. From the table which is given to us total rainfall for the entire time period can be calculated. It is calculated as 14.75 centimetres and the corresponding hyetograph is plotted. Now, what we need to determine? We have been given the runoff depth, we need to calculate the $\phi-index$ value for this particular storm.

So, for this what we will be doing? We need to make certain initial guess related to $\phi-index$. So, initially thinking of the initial abstractions and the high value of infiltration in the beginning of the storm, we can assume a certain $\phi-index$ value between certain time interval. Here what I am going to do I am going to assume a $\phi - index$ value between 0.5 and 1 centimetres per hour.

So, we are going to assume ϕ is equal to 0.75 centimetres per hour. So, it can be up to you if you are a very experienced person, you are having an amount of actual runoff and also rainfall value from this rainfall value what should be the abstractions which has to be subtracted to get this much of runoff value. From experience you will be getting that value your initial guess may become correct but for a beginner we need to start like this. We have to assume a $\phi - index$ value here I am assuming 0.75 centimetres per hour as the first guess for $\phi - index$.

So, if $\phi - index$ is 0.75 centimetres per hour, you can understand that from 0 to 1 hour that is one unit is marked at the centre it represents this time interval is one hour. So, during the first hour whatever rainfall is occurring that is getting infiltrated or it is lost as initial abstractions and also, the last ordinate also that is corresponding to 7 hours to 8 hours, the rainfall corresponding to that particular time interval is also lost as infiltration or abstraction. So, whatever comes above will be taken as the runoff depth. So, what we will do corresponding to this assumption that is ϕ is equal to 0.75 centimetres per hour we will calculate the runoff depth then we will compare with the actual runoff depth, if both are matching our initial guesses correct. If it is not matching then we may have to go for second trial.

So, we can start solving the problem. So, estimated runoff corresponding to ϕ value is 0.75 centimetres per hour can be calculated that is this ordinate will be going as abstraction corresponding to first hour and last 1 hour. Above that that is above this $\phi - index$ value that is contributing as the runoff depth. So, this is calculated as estimated runoff is coming out to be 9 centimetres. This is similar to that of the previous problem in the previous problem $\phi - index$ value is given to us. Here in this case, we are making an initial guess of $\phi - index$ value between 0.5 and 1 or it can be assumed between 1 and 1.5 also based on your assumption and with the calculated estimated value of runoff depth, you can change the initial guess value.

So, here in this case with the $\phi - index$ value 0.75 centimetres per hour our estimated runoff value is 9 centimetres. So, this estimated value of 9 centimetre is more than that of the actual runoff. Actual runoff is given out to be 6 centimetres and estimated is 9 centimetres. So, we can understand that with the assumed $\phi - index$ value that is the constant rate of abstraction which is assumed as 0.75 centimetres per hour is producing a runoff depth of 9 centimetres which is more than that of the actual runoff. So, the abstractions which is taking place is less so, that value need to be increased than that of the initial guess. Therefore, ϕ should be greater than 0.75 centimetres per hour.

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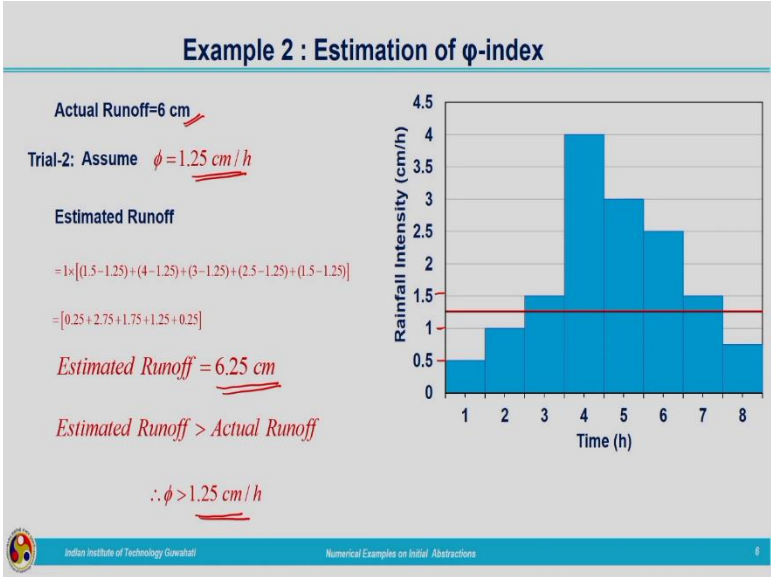

So, in the next guess what we will be doing same figure we are going to assume a $\phi - index$ value of 1.25 centimetre per hour. From where this 1.25 is coming? Initial guess was between 1 and 0.5 and second guess we are going to make between 1 and 1.5. That interval rainfall intensity for which the $\phi - index$ value will be constant which gives the actual runoff depth that we need to determine. So, initial guess was giving us an overestimated value of runoff which was more than that of the actual runoff. So, what we need to do? We need to increase the constant rate of abstraction that is why we have increased the $\phi - index$ value from 0.75 centimetres per hours to 1.25 centimetres per hour.

Now, we will repeat the computation in the similar way as we have done previously. So, estimated runoff will be coming out to be 6.25 centimetres. So, here also you can see actual runoff is 6 centimetres and our estimated value is more than that of the actual runoff. So, $\phi - index$ should be greater than 1.25 centimetres per hour because the abstraction should be more then only the runoff calculated will be less because we need to reduce the computed runoff value then only it will be matching with the actual runoff depth.

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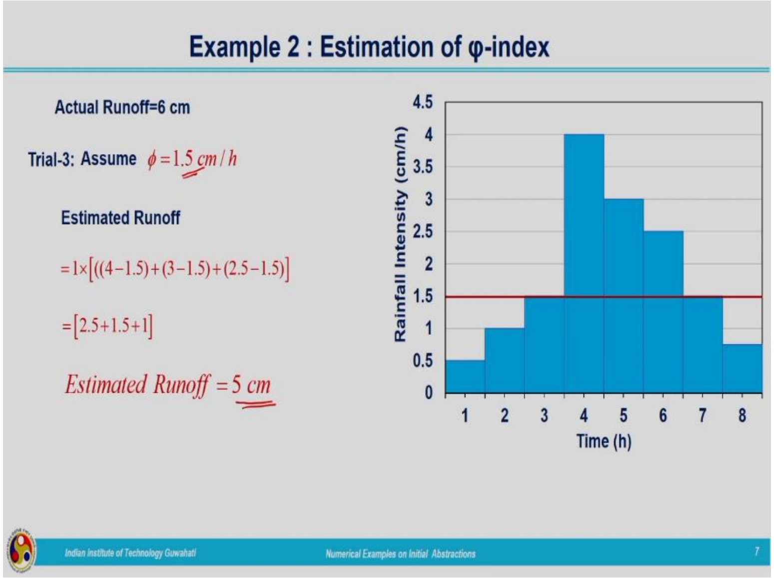

So, in the third trial, we will assume a $\phi - index$ value of 1.5 centimetres per hour. So, trial three our assumption is ϕ is equal to 1.5 centimetres per hour. So, estimated runoff will be around 5 centimetres. So, here you can understand that when the constant value of abstractions came out to be 1.5 centimetres per hour or the $\phi - index$ value of 1.5 centimetres per hour produced a runoff depth of 5 centimetres that is less than that of the actual runoff depth which is occurring there at the outlet of the watershed. So, what we have to do? We have to reduce the $\phi - index$ value. In the previous two assumptions previous two guesses which we have made estimated runoff depth was calculated to be more than that of the actual runoff depth. Here in the third trial, it is found out that it is less than that of the actual runoff depths. So, abstractions should be reduced. For a value corresponding to ϕ is equal to 1.25 centimetres per hour, we got an overestimated value of runoff depth.

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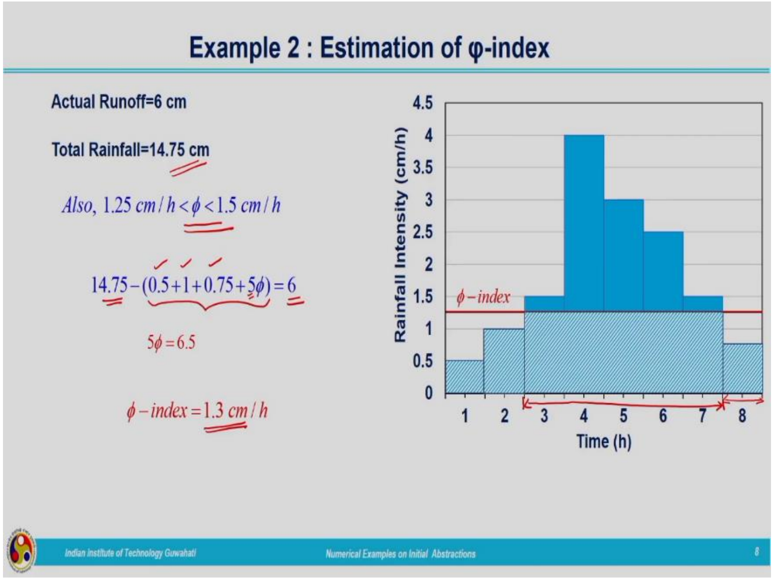

In the case of $\phi - index$ value ϕ is equal to 1.5 centimetres per hour it was an underestimated value that is the value of ϕ should be between 1.25 and 1.5 centimetres per hour and this much of water will be lost as abstractions and beyond what is coming that is producing the direct runoff, that value we need to quantify. So, we know if this is ϕ, this red line is representing ϕ and that is corresponding to how many hours so, we can easily understand that from time 0 to 2 hours entire rainfall is lost as abstractions and also, from 7 to 8 hours also, the rainfall is lost as abstraction but in between 2 hours to 7 hours that is from here to here, we are having constant rate of abstraction represented by $\phi - index$ value. So, once we deduct that abstractions in terms of ϕ value from the total rainfall, we should get the runoff depth. So, that is what I am writing over here, 14.75 centimetres is our total rainfall, total rainfall minus total abstractions will be giving you a runoff depth of 6 centimetres, i.e.,

$$14.75 - (0.5 + 1 + 0.75 + 5\phi) = 6$$

So, how these abstractions are calculated? For 0 to 1 hour it is 0.5 centimetre 1 to 2 hours it is 1 centimetre and 7 to 8 hours it is 0.75 centimetres and in between from 2 to 7 hours, we are having a constant abstraction of value equal to ϕ. So, for that we can compute the quantity by multiplying the $\phi - index$ with the corresponding time interval. So, how many hours are there in between 2 to 7 it is 5 hours and constant rate of abstraction is 5 centimetres per hour.

So, ϕ multiplied by ϕ plus abstractions corresponding to other time intervals together will be the total abstraction that abstraction subtracted from the total rainfall will be giving you the direct runoff depth that is 6 centimetres. So, by making use of this formula, you can calculate $\phi - index$ value as 1.3 centimetres per hour or you can proceed in the way as we were making the initial guesses. So, that way next trial you can go ahead but how many trials you may have to proceed, we do not know, but here one thing is certain that our $\phi - index$ value is between 1.5 and 1.25. So, we got how much should be the abstractions. So, we are assuming ϕ as the $\phi - index$ value and we know the time intervals corresponding to that constant rate of abstraction and corresponding to the abstraction value less than $\phi - index$ value. So, total abstractions we will calculate in terms of $\phi - index$ and that we will deduct from the total rainfall value which will be equated with the total runoff depth at the outlet of the watershed. So, that way we can determine the $\phi - index$ value. So, in these types of problems, you need to have runoff depth or $\phi - index$ given to you. So, these types of approaches are applicable to gauged catchments.

Now, third method was related to runoff coefficient. Runoff coefficient is we know how to calculate the formula is given. So, I am not working out separate problem related to that, let us directly move on to the numerical example related to infiltration equations. So, here what we are going to do how those equations can be utilized for finding out the abstractions and after that deducting those abstractions from the rainfall depth to calculate the direct runoff depth.

So, these types of methods that is computing abstractions by making use of infiltration equations assumes that all the abstractions are taking place due to infiltration only, all other abstractions are neglected and by making use of the infiltration equations, we will calculate the total volume of water getting infiltrated that we will be deducting from the total rainfall depth to get the excess rainfall. Any of the equations can be utilized if the data is available. Here we are going to deal with the Horton’s equation.

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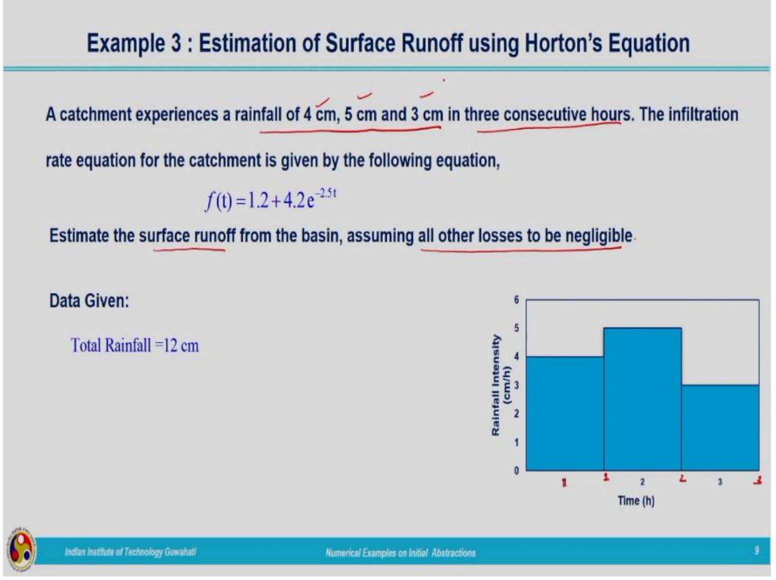

So, let me read out the question. A catchment experiences a rainfall of 4 centimetre, 5 centimetres and 3 centimetres in three consecutive hours. The infiltration rate equation for the catchment is given by the following equation that is a $f(t) = 1.2 + 4.2e^{-2.5t}$. Estimate the surface runoff from the basin assuming all other losses to be negligible.

So, here you can see infiltration rate is represented by means of an equation. That equation is given to you and rainfall depth is also given to you for continuous constitutive 3 hours. Rainfall in terms of depth is given to you that is hyetograph is given to you and the infiltration rate equation is also given to you. Once the quantity of water corresponding to that much of infiltration is quantified, that value can be deducted from the total rainfall value to get the excess rainfall which is equivalent to the direct runoff. So, let us revisit into the data given this is a rainfall hyetograph which is given to us. So, this one is representing from zero to one hour, one to two hours and two to three hours. So, with that interval how much is the rainfall occurred that is what is shown over here. This is our rainfall hyetograph. Total rainfall you can calculate 4 centimetres, 5 centimetres and 3 centimetres. So, this is coming out to be 12 centimetres.

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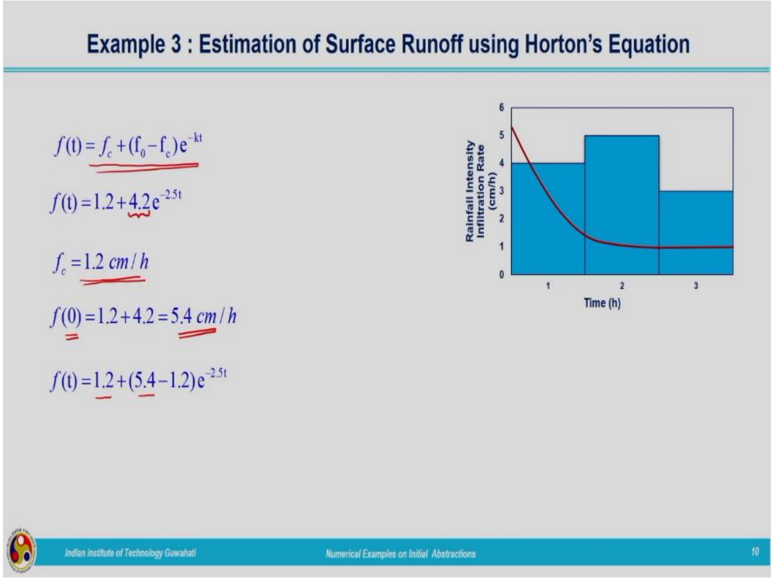

Now, infiltration equation is given to you in the form of Horton's equation. You might be remembering Horton's equation which we have covered in third module.

$$f(\text{t}) = f_c + (f_0 - f_c)\,\text{e}^{-\text{kt}}$$

This is the form of Horton's equation. So, the given equation is similar to that of this equation, you can compare each other

$$f(\text{t}) = 1.2 + 4.2\,\text{e}^{-2.5\text{t}}$$

So, here we can take f_c that is the constant rate of infiltration equal to 1.2. After comparing these two equations, we can understand that f_c is 1.2 centimetres per hour. Now, this 4.2 is representing the value corresponding to $f_0 - f_c$. $f_0 - f_c$ is 4.2. f_c is 1.2. So, we can get the value corresponding to f_0 or one more way to calculate f_0 is that when time t is equal to zero how much will be the infiltration that is the value corresponding to f_0, initial infiltration is represented by f_0. So, we can calculate

$$f(0) = 1.2 + 4.2 = 5.4\ cm/h$$

$$f(\text{t}) = 1.2 + (5.4 - 1.2)\,\text{e}^{-2.5\text{t}}$$

f_c is 1.2, f_0 is 5.4. So, this is our Horton's equation. Now, that we can plot over here. When we plot this, the curve will be looking like this, infiltration curve represented by Horton's equation by making use of the values which is given by this equation we have utilized to plot this curve.

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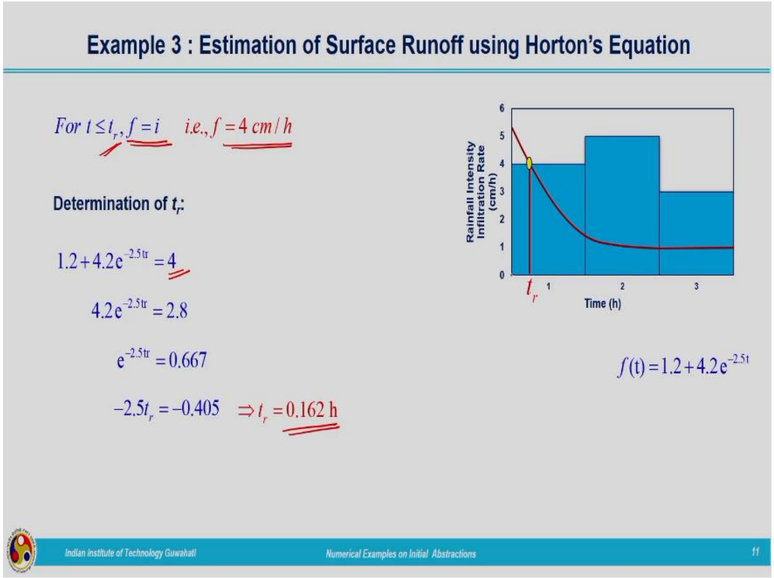

So, now you can see up to a certain point that point is corresponding to the meeting point of the infiltration curve and the rainfall hyetograph. So, when we were discussing about the potential infiltration and actual infiltration, we have seen that if *f* value is greater than intensity of rainfall, all the water which is falling as rainfall will be infiltrated into the ground. So, here you can look at the curve, infiltration curve and the rainfall hyetograph up to a certain time rainfall intensity is less than that of the rate of infiltration. So, till that time whatever rainfall is falling on the ground will be infiltrated into the ground.

After that particular time here, which is marked by this yellow dot, you can see that infiltration is drastically reduced and rainfall which is experienced by the catchment is more than that of the infiltration rate. So, first we need to calculate the value of time corresponding to this meeting point of the infiltration curve and the rainfall intensity hyetograph that is corresponding to that time whatever rainfall is occurring that is converted to abstractions. So, that can be denoted by the time t_r. So, this we need to determine now.

So,

$$For\ t \le t_r, f = i \quad i.e., f = 4\ cm/h$$

Now, we can determine t_r that is we are going to make use of the equation infiltration rate equation, we know the infiltration rate corresponding to the value of time t is equal to t_r. So,

$$1.2+4.2e^{-2.5t_r}=4$$

From this we can calculate the value corresponding to t_r

$$4.2e^{-2.5t_r}=2.8$$

$$e^{-2.5t_r}=0.667$$

$$-2.5t_r=-0.405$$

$$t_r=0.162 \text{ h}$$

So, that we can understand initially just starting from zero to 1. So, it is less than 1 hour. It is calculated to be 0.162 hours. At 0.162 hours or before t less than 0.162 hours whatever rainfall is occurring, it has lost as abstractions. When t is more than this 0.162-hour whatever rainfall is coming from that the infiltration we are detecting we will get the excess rainfall.

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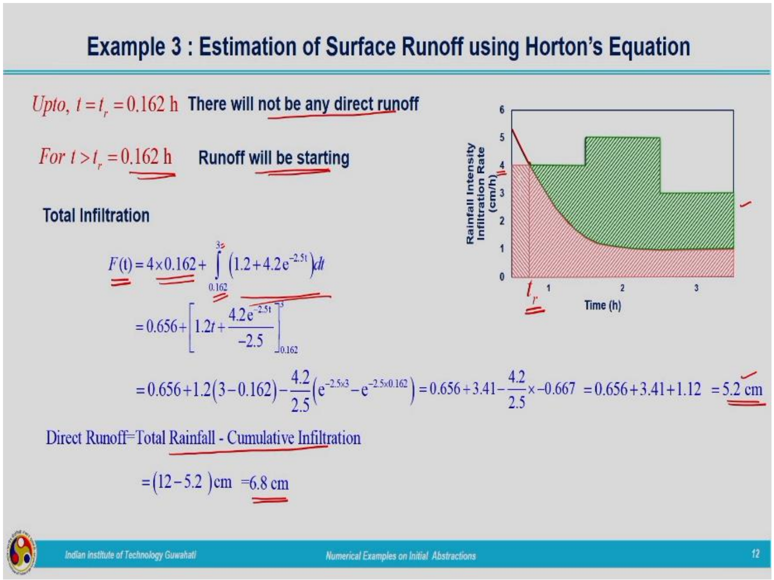

So, upto $t=t_r=0.162$ hours there will not be any direct runoff. So, that I am showing by means of hashed areas. So, this much is the that is upto $t=t_r$ whatever rainfall is occurring that has been lost as abstractions. And now the area which is coming under the infiltration rate curve that will be contributing towards the subsurface flow that is infiltrated into the ground. Remaining water only contributing towards the surface runoff that may need to quantify now. So, for $t>t_r=0.162$ hours our runoff will be starting. So, we need to quantify the rainfall value after 0.162 hours which is contributing towards the runoff value. So, the runoff will be starting after this $t = t_r$. So, that portion of the rainfall data rainfall hyetograph which is marked by means of these green hatched lines is representing our excess rainfall or the direct runoff.

So, how can we get the volume of water corresponding to direct runoff? Now, we know that we have demarcated the region between the abstractions and the excess rainfall. Now, what we have to do? We have to quantify the total amount of water which is infiltrated that can be deducted from the total rainfall which will be representing our direct runoff. So, we need to quantify the total volume of water or total depth of water which is infiltrated. So, that is nothing but our cumulative infiltration. So, total infiltration is represented by *F(t).* So, we know corresponding to t_r the rainfall intensity is 4 centimetres per hour. So, we can understand that this much area that is 4 into 0.162 is completely lost as abstraction and from time *t* is equal to 0.162 to three hours that is till the end of rainfall, cumulative infiltration can be calculated by integrating the infiltration rate that is what we are doing. Before the time *t* less than t_r entire rainfall is infiltrated. So, it_r will be considered as the cumulative infiltration up to the time of ponding. So, that time after *t* greater than t_r whatever is coming from that we need to calculate the cumulative infiltration and both should be summed up to get the total infiltration that we will be deducting from the total rainfall value.

So, time durations we are dividing into two parts that is 0 to t_r and t_r to till the end of the rainfall that is t_r is 0.16 to 0 to 0.162 whatever intensity of rainfall is there entire value is converted to infiltration. So, that total value of infiltration up to time *t* is equal to 0.162 can be calculated by using it_r, which will be giving you the cumulative infiltration upto $t = t_r$. From time $t = t_r$ to the end of the rainfall, we can calculate the cumulative infiltration by integrating the infiltration rate equation that is *f(t)* can be integrated between that time duration which will be giving us the cumulative infiltration corresponding to time between t_r to t_{max}. So, that is what is written over here that is

$$F(\mathrm{t}) = 4 \times 0.162 + \int_{0.162}^{3} \left(1.2 + 4.2\,\mathrm{e}^{-2.5\mathrm{t}}\right) dt$$

So, when we integrate that and after that if we sum up, we will get

$$F(t) = 0.656 + \left[1.2t + \frac{4.2\,\mathrm{e}^{-2.5\mathrm{t}}}{-2.5}\right]_{0.162}^{3}$$

$$= 0.656 + 1.2(3 - 0.162) - \frac{4.2}{2.5}\left(e^{-2.5\times3} - e^{-2.5\times0.162}\right) = 0.656 + 3.41 - \frac{4.2}{2.5}\times -0.667$$
$$= 0.656 + 3.41 + 1.12$$
$$= 5.2cm$$

This you can work out and see whether you are getting it as 5.2 centimetres. So, the total depth of infiltrated water is calculated to be 5.2 centimetres and direct runoff is

Direct Runoff=Total Rainfall - Cumulative Infiltration

i.e., total rainfall for that period how much it is minus cumulative infiltration for that time period that will be giving you the direct runoff depth. So, total rainfall we know 12 centimetres and cumulative infiltration we have calculated 5.2 centimetre. So,

$$= (12 - 5.2) = 6.8\text{cm}$$

So, by making use of infiltration equations, whether it is Horton's equation or Green-Ampt equation or Phillip's equation if the parameters corresponding to those equations are available to you, you can calculate the cumulative infiltration how much it is coming. So, that cumulative infiltration if you are deducting from the total runoff value you will get the direct runoff. But here you need to understand at what time the ponding is occurring. That detailed explanation we have seen with the help of Green-Ampt equation time to ponding and after ponding how much infiltration can be occurred that also we have seen the equation by using Green-Ampt equation. In the similar way here also, we need to find out at what time that the time corresponding to infiltration rate equal to intensity of rainfall that we need to determine. Till that time entire water is infiltrated into the ground after that water will be contributed towards runoff. So, that way we need to calculate the cumulative infiltration and after getting the cumulative infiltration value that we will be deducting from the total rainfall value to get the runoff depth.

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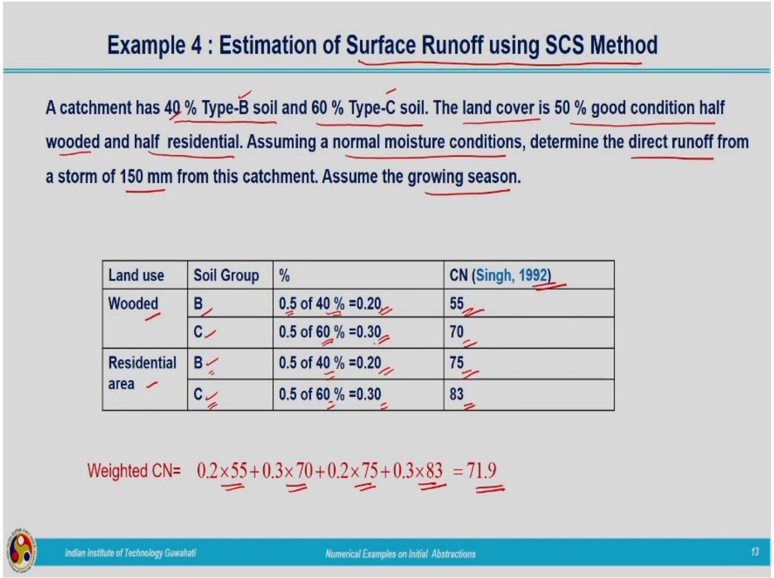

Now, let us move on to the fourth example, it is related to estimation of surface runoff using a SCS method that is our SCS curve number method. So, the question is a catchment has 40 percentage type B soil and 60 percentage type C soil, the land cover is 50 percentage good condition, half wooded and half residential. Assuming a normal moisture conditions, determine the direct runoff from a storm of 150 millimetre from this catchment, assuming the growing season.

When we were discussing about SCS method, SCS curve number method we have seen the moisture content is related to antecedent moisture content when we were explaining, corresponding rainfall values have been given in a table, the growing period and also dormant period dormant condition and also growing stage is given in that.

So, here in this problem it is related to growing season, corresponding to that the value should be taken from the table. So, the catchment description is there in this catchment we are having 40 percentage of type B soil and 60 percentage type C soil, different types of soil are present in the catchment. So, depending on the soil characteristics, SCS has provided for groups A, B, C, D. Out of those four groups in this catchment type B soil and type C soil is present and it is given that 40 percentage of the area is having type B soil and 60 percentage type C soil. The land cover is also given because the curve number value is dependent on the soil property and the type of soil and also land use properties. So, land cover details are given as 50 percentage of good condition half wooded and half residential. So, 50 percentage land is there out of that 25 is wooded and 25 is residential. So, two areas we can divide the entire catchment into two areas, 50 percentage, 50 percentage and in each area, we are having half of wooded in good condition and half residential. So, based on these land-use classifications, we need to take the curve number from the table which is given in the textbook and this is based on normal moisture condition that is AMC II, Antecedent Moisture Condition II is considered here and if it is something related to dry season dry condition and the saturated condition we have to go for AMC I and AMC III. So, it is given that normal condition so, we need to go with the AMC II condition. So, let us find out the curve number for this particular land use.

So, land use is given we can find out the curve number first. So, given land use is wooded and residential area. Soil group in both these land use condition we are having soil Group B and soil Group C. So, that way we are having soil Group B and C in both the land use condition: wooded condition also soil Group B and C present residential area also soil Group B and C are present. Now, percentage of this area it is already given 50 percentage of good condition half wooded half residential. So, initially the catchment is 40 percentage type B and 60 percentage is type C. So, that condition we will apply to both wooded land use and also residential area. So, we need to find out the percentage of area. So, the entire area is divided into 50 percentage that is 0.5 of 40 percentage type B soil and 0.5 of 60 percentage type C soil in wooded land use. In the similar way corresponding percentages for residential area also, that we have calculated it is found out to be 0.2, 0.3 and 0.2 and 0.3 for residential area also.

Now, we can compute the curve number corresponding to a wooded area. Curve number corresponding to wooded area I have taken from Singh, 1992 textbook. So, for wooded area for type B soil it is 55, wooded area for type C soil it is 70 and residential area soil Group B it is 75 and residential area soil Group C it is 83. So, these tables are available to you in any of the hydrology textbooks which is covering SCS method. Majority of the basic textbooks are covering SCS method for estimating direct runoff, from the textbook you can take the values corresponding to curve number but now the issue is that not a single value of curve number is representing the catchment. We are having four different groups two types of soil and two types of land use areas. Based on that we are having different percentage of land areas which is having different curve number value. So, we need to calculate the weighted curve number value. So weighted curve number value can be calculated as

$$Weighted\ CN = 0.2\times 55 + 0.3\times 70 + 0.2\times 75 + 0.3\times 83 = 71.9$$

All will be summed up to get the weighted curve number it is coming out to be 71.9. So, from the value of 71.9 you can understand it is a natural area. If the area is a water body or a completely paved impervious area, CN value will be 100. For any other areas the value will be between 0 and 100. So, here the weighted curve number value is calculated to be 71.9. So, once curve number value is known to you curve number values available to you, you can calculate the potential retention represented by *S*.

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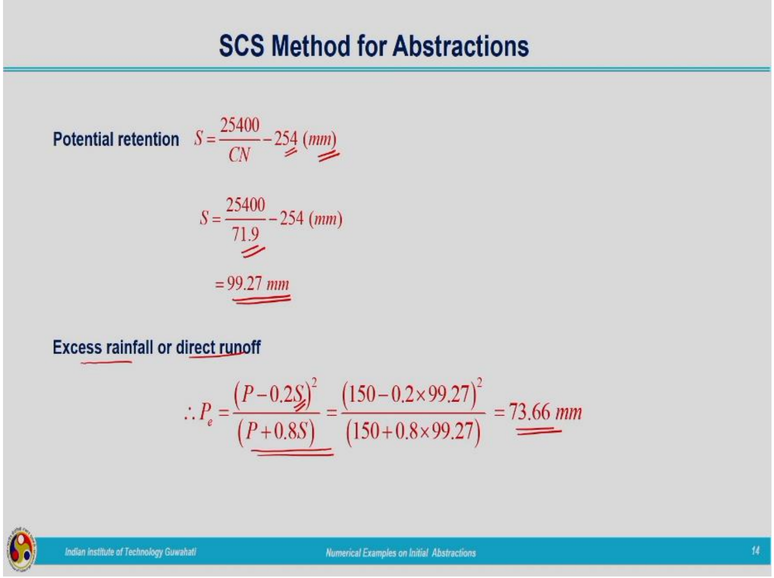

So, we can calculate potential retention *S*, given by this formula.

$$S=\frac{25400}{CN}-254\ (mm)$$

Here, we will get *S* in terms of millimetres because we have already made use of the multiplying factor that is the inch conversion to centimetres and that is again converted to millimetres that is why it is having 25,400 and 254. If it is in centimetres, it will be 2540 and 25.4 and if it is in inches, this factor will not be coming, it will be 1000 and 10. So, you need to be very careful about the unit. So, here all the units are in SI unit so, you can convert it into millimetres or centimetres.

Here we are going to substitute the curve number value *CN* is equal to 71.9. So, you can calculate the potential retention as

$$S=\frac{25400}{71.9}-254\ (mm)=99.27mm$$

S is calculated to be 99.27 millimetres. So, now you can calculate the excess rainfall or the direct runoff by using the formula given by SCS curve number technique. This is the formula for calculating excess rainfall or direct runoff

$$P_e = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

This we have seen in the previous lecture, how we have reached at this particular form of the equation. So, here what we have to do we have to just substitute corresponding to the value of potential retention S.

So, once we substitute, we can calculate the excess rainfall which is equivalent to direct runoff as

$$P_e = \frac{(150 - 0.2 \times 99.27)^2}{(150 + 0.8 \times 99.27)} = 73.66mm$$

So, the runoff at the outlet of this watershed which is consisting of wooded and the residential area and which also includes different soil groups B and C, we can get the runoff value corresponding to that particular catchment as 73.66 centimetres.

So, here all the methods I have explained related to excess rainfall or direct runoff computation. First two examples were related to gauged catchments and third and fourth examples can be utilized for ungauged catchments. So, in the gauged catchments, we can make use of any of the techniques, but in the ungauged catchments, there are limitations in using phi index value because for determination of $\phi - index$ value, we need to have the value corresponding to the runoff depth based on that only we can calculate the $\phi - index$ value that is the constant rate of abstraction from the rainfall. So, if the direct runoff depth is available to you, you can calculate the $\phi - index$ value and based on that $\phi - index$ value you can compute the excess rainfall and other two problems were related to infiltration equation and also SCS curve number method. So, please try to solve more problems, numerical examples related to this.

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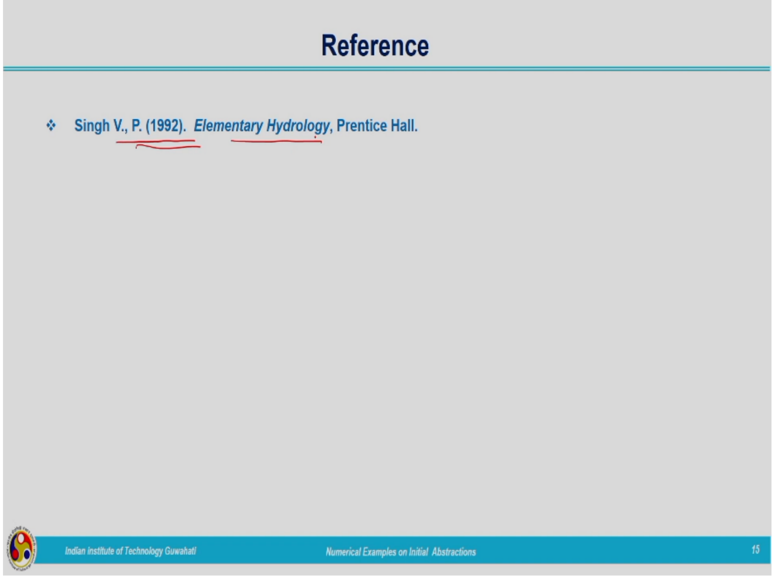

Here I am winding up this topic. Reference related to these SCS method that is the curve number all these things are taken from the textbook of Professor V.P Singh elementary hydrology. Any of the textbooks related to hydrology will be containing this table. So, different soil group details all those things when and the topic of SCS is explained along with that those tables also given. So, here I am winding up this lecture. Thank you.